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Proceeding Paper

Estimation of Crop Water Requirements and Crop Coefficients of Multiple Crops in Semi-Arid Region by Using Lysimeters †

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Abstract: Pakistan is primarily an agricultural nation. Agriculture is the backbone of our economy, and it accounts for around 19.3 percent of our total gross domestic product. Pakistan ranks among the world's top 10 producers of wheat, maize, rice, cotton, and sugarcane, according to the United Nations Food and Agriculture Organization. It also cultivates edible oil seed crops. Water is the most important parameter of which we use for cultivation of various crops. Pakistan is a country where irrigation water is extremely valuable. Irrigation schedule affects a crop's agronomic and economic viability. For the sake of water conservation as well as enhanced crop yields, it is essential. Based on monitoring soil water levels and crop water requirements, irrigation scheduling can be used to apply water for cultivation in accordance with predefined schedules. How much water to be apply when to a particular crop depends heavily on the kind of soil and weather circumstances this is an important practical component of irrigation. Crop water requirements and crop coefficients are the most significant parameters that must be determined precisely at local levels to determine how much water is required for crop growth at various stages. There are many approaches for determining crop water requirements, but Lysimeters is the most effective. Lysimeters are devices that are routinely used to determine agricultural water requirements all around the world. The water required by different crops like wheat, oat, carrot, and maize at different crop growth stages was determined using non-weighing type Lysimeters in this study. To compute the crop coefficient, the Penman–Monteith equation was used, which takes into account daily mean temperature, wind speed, humidity, and solar radiation as inputs to the equation. Reference values for evapotranspiration during this period are taken from the metrology station. Water requirement of wheat crop of variety Fakhre Bhakhar and Anaj-17 are 361.8 mm and 379.5 mm and their crop coefficients or kc values were in between 0.79 to 1.19 and 0.27 to 1.27 respectively. Water required by carrot crop 94.42 mm and its crop coefficients taken out from the study are in between 0.82 to 1.16. Water requirement of maize crop for hybrid variety was found to be 403.07 mm and its crop coefficients were in between 0.62 to 1.07. Water required by oat crop throughout its season with including three time harvesting is 331.89 mm and its crop coefficient is 0.66 to 1.13. Water requirements of each crop and crop coefficients calculated by this study are close enough to recommend by FAO.

Keywords: Lysimeters; crop water requirements; crop coefficients; climate change; water resources

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1. Introduction

Evapotranspiration and moisture standards for crops are two important factors limiting the development of agricultural practices. Roots of crops that are submerged or filled with groundwater will be depleted, and the crop will not grow. This will make the crop fail. Lysimeters are used to figure out how much water plants lose through evaporation. They record the amount of precipitation and water that is delivered to the crop through irrigation as well as the amount of water that is lost through the soil due to percolation. This information can be used to figure out how much water the crop needs and how much evapotranspiration it needs. Lysimeters are the first and most important instruments, tanks or vessels that can set limits on how much water can stay in the soil and measure soil water balance, how much water goes vertically, or how much water is in the soil.

In agriculture, crop water requirements are defined as the depth of water required to meet the water loss through evapotranspiration of a disease-free crop growing in large fields under intolerable soil conditions, including soil water and fertility status, and achieving full grains production potential under the given environmental conditions (including soil water and fertility status). Identifying water requirements and crop coefficients is critical for irrigation scheduling and agricultural water management in field management. The assessment of crop evapotranspiration (ETc), which is dependent on crop features, management techniques, crop development stage, as well as climate and environmental circumstances, is directly related to crop water requirement. There are two ways for calculating crop evapotranspiration (ETc) direct and indirect. In the direct technique, Lysimeters are used to estimate ETc, but in the indirect method, reference evapotranspiration (ET) and crop coefficients (kc) are being used for crop water requirements of the crop. (Shahrokhnia and Sepaskhah, 2013).

In terms of crop variation and output, water is the most significant limiting factor. The most of water resources have been devoted to agricultural irrigation. The proper use of irrigation water is becoming increasingly crucial as a means of dealing with the impending water crisis. An irrigation system ensures that plants receive the proper amount of water at the appropriate time for growth. Subsidized irrigation is the most important aspect of irrigation because it is used to augment natural rainfall in locations where the amount of rain falls irregularly or infrequently. Irrigation is used in arid places when the soil is extremely fertile and can support crop productivity, but there is little or no rainfall. Total irrigation is the name given to this method of irrigation. Due to a lack of irrigation, crops suffer from water stress, which lowers their yield. Plant nutrients can be leached, and runoff and soil erosion can cause pollution of water sources if excessive irrigation is applied. In most cases, factors such as soil texture, rooting pattern, topography, evapotranspiration (ET) rate, rainfall, and crop type and/or development stage are likely to influence the frequency of irrigation. Carrot production can benefit from a more efficient use of irrigation water. Irrigation scheduling has the potential to increase irrigation efficiency, decrease irrigation costs, and reduce water opportunity costs. Similarly, another study found that boosting carrot production in a sustainable way relies on appropriate irrigation design, management, and scheduling. Thus, scheduling irrigation in accordance with crop water needs reduces the risk of under or over watering. Crop failure and fertilizers leaching beyond the root zone are also reduced, and growers see an increase in profit under well-established crop water need references. Consequently, the goal of this review study is to combine knowledge on carrot water requirements, irrigation schedules, and water use efficiency by combining material from various literatures on the subject (Beshir, 2017).

The evaluation of the water requirements of a crop begins with the collection of fundamental data, which is represented by the estimation of evapotranspiration (ET). One of the most common approaches to calculating ET is based on what is known as the "crop coefficient", which is defined as the ratio of total evapotranspiration to reference evapotranspiration ET0. This approach is very popular. The recent standard methods of the F.A.O. have shown that the value of the crop coefficient is connected to canopy factors reflecting the crop growth stage. These variables include canopy height and fractional vegetation cover. This relationship holds true under given climatic conditions. (D'Urso & Calera Belmonte, 2006).

Soil–plant–atmosphere water cycling includes evapotranspiration (ET), which is a major component. Water-related studies and applications, such as irrigation system design, irrigation scheduling, water resource planning and management, water allocation, water balance computation, crop yield forecast, and so on, rely heavily on its trustworthy data. Although a variety of methods exist for measuring ET, they are time-consuming, expensive, and labor-intensive. As a result, it is typically calculated as the product of reference crop evapotranspiration (ET0) and crop coefficient in the well-known two-step approach (Allen et al., 1998) (Liu et al., 2017).

2. Materials and Methods

2.1. Study Area

In the semi-arid climate of Faisalabad, experimental research was carried out to determine the water requirements and crop coefficients of wheat, oat, carrot, and maize. For this study, experimental trails are being cultivated in the faculty of agricultural engineering and technology's experimental site at the University of Agriculture Faisalabad. This study was carried out at an experimental site with 12 Lysimeters.

Figure 1. Experimental site of 4 Lysimeters (University of Agriculture Faisalabad Pakistan).

Figure 2. Experimental site of 8 Lysimeters (University of Agriculture Faisalabad Pakistan).

2.2. Data Collection and Analysis

Irrigation Scheduling

Sandy loam is the soil in each lysimeter Sandy loam soil has a field capacity of 22% and a permanent wilting point of 8%. At 50% depletion of soil moisture, each crop will be irrigated. In order to re-establish field capacity, irrigation is applied when soil moisture levels fall below 15%. Soil moisture sensors detect when irrigation should be applied based on the amount of moisture present in the soil. As a result, irrigation is applied anytime the soil moisture percentage in each lysimeter approaches 15%. For irrigation purposes, the depth of water needed to re-establish field capacity is measured using the following formula:

$$\text{Depth} = d = (FC - M.C)/1oo \times R.Z$$

in which,

d = Depth of water required for irrigation
FC = Field capacity
M.C = Moisture content
R.Z = Root zone depth of crop

Flood irrigation has a 30 to 40 percent efficiency rate, but our field is levelled and tiny, therefore we suppose that water is applied at a 70 percent efficiency rate. As a result, the actual depth required to reach field capacity is once again a factor.

$$D = d/0.7$$

In order to figure out how long it will take to irrigate a certain area, one simply needs to know the discharge area of a lysimeter and the depth of that area.

$$T = (A \times d)/Q$$

T = time required for irrigation
A = area of lysimeterd
D = depth required
Q = discharge of pump

As a result, the amount of time it takes to re-establish soil's field capacity (FC) is given by the above equation.

ETo data is critical in determining crop coefficients and water requirements. ETo data The ETo value for each month or each day might vary based on a variety of factors, including the weather, the time of day, and wind velocity. It is from the UAF meteorological observatory that data of cropping months' evapotranspiration since 2013 to 2021 is collected. As a result, an average of 8 years' worth of ETo data is utilized to estimate crop water needs and crop coefficients. The amount of water a crop needs from seeding to harvest is known as the crop water requirement. This water is required by crops at several stages of growth, including planting, maturation, and flowering. It is possible to estimate the amount of water a crop will require by summing all the irrigation water used to reach the soil capacity and the actual rainfall.

$$CWR = TAW + Re$$

CWR = Crop water requirement
TAW = Total applied water
Re = Effective rainfall

Thus, by above relation crop water requirement is calculated of each crop sown in that experiment i.e., Wheat, Oat, Carrot and Maize. Crop coefficients or Kc can be calculated by simple relation between ETc and ETo. The relation for calculation of crop coefficients is recommended by penman montieth given as,

$$ETc = ETo \times Kc$$

$$\text{Thus, } Kc = ETc/ETo$$

By using above relation between ETc and ETo kc for wheat, oat, carrot, and maize were calculated.

3. Results and Discussion

Wheat, Carrot, Oat and Maize crops in Faisalabad's semi-arid climate were analyzed using Lysimeters to determine crop water requirements and crop coefficients for the year 2021–2022.

3.1. Soil Characterictics

The movement of soil along the water's surface is determined by the soil's physical properties. Infiltration rate, field capacity, permanent wilting point, bulk density, and water holding capacity of soil are all included.

3.2. Soil Bulk Density

In terms of physical properties, bulk density refers to the soil's composition, the number of pores, and how much organic matter is there. The bulk densities in the treated plots were computed using ASAE Norm S269.4 and the results were analyzed. Between 1.52 and 1.60 g/cm^3 was the bulk density range.

3.3. Soil Infiltration Rate

Before the analysis began, soil penetration intensity was determined at the testing site in September 2021. If runoff is to be avoided, the irrigation rate must be less than or equal towards the infiltration rate. Infiltration rates ranged from 0.70 to 0.83 cm/h. Soil infiltration has a direct effect on the movement of water in the soil profile. A decrease in soil porosity was seen as a result of clay particle dispersion and growth in irrigation water containing higher concentrations of Na ions, both of which are caused by irrigation water of low quality.

3.4. Effect of Climate on Eto

The temperatures are at increase throughout the region especially in the northern parts of the country. Pakistan has an agrarian economy where climate change and the consequent threat of global warming have become a great challenge. The principal weather parameters affecting evapotranspiration are radiation, air temperature, humidity, and wind speed. In a warming climate, increased evapotranspiration may shift the fraction of precipitation that runs off as surface water or infiltrates to the subsurface as recharge. In a warming climate, increased evapotranspiration may shift the fraction of precipitation that runs off as surface water or infiltrates to the subsurface as recharge.

3.5. Determination of Effective Rainfall

The amount of rainfall water that is accessible for use by plants is referred to as "effective rainfall." The formula provided by FAO is used to determine this value. Here are the formulas for calculating effective rainfall.

$$Pe = 0.8P - 25 \quad \text{if } P > 75 \text{ mm}$$

$$Pe = 0.6P - 10 \quad \text{if } P < 75 \text{ mm}$$

Table 1. Effective rainfall.

Month	P (mm/month)	Formula	Pe (mm/month)
December	20	Pe = 0.6P − 10	2
January	48.4	Pe = 0.6P − 10	2
February	2.5	Pe = 0.6P − 10	0
March	75	Pe = 0.8P − 25	35
April	57	Pe = 0.6P − 10	24.2
May	54	Pe = 0.6P − 10	22.4

3.6. Water Requirement and Kc of Wheat Variety Fakhre Bhakkar

Wheat crop sown at 1 December 2021 and harvested at 28 April 2022. The water required by wheat crop during this season is 361.8 mm. The Kc value for wheat variety Fakhre Bhakkar varies from 0.79 to 1.19 varies during whole crop season.

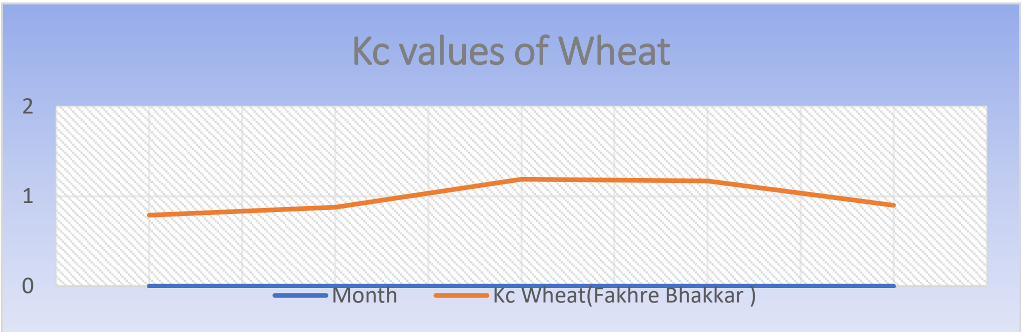

Figure 3. Crop Coefficients of Wheat Fakhare Bhakhar.

3.7. Water Requirement and Kc of Wheat Variety Anaj-17

Wheat crop sown at 1 December 2021 and harvested at 28 April 2022. The water required by wheat crop during this season is 379.5 mm and Kc value is between 0.87 to 1.27.

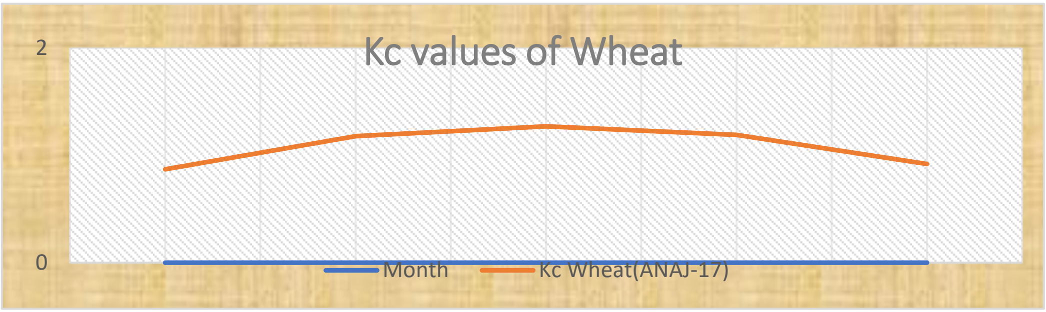

Figure 4. Crop Coefficients of Wheat Anaj-17.

3.8. Water Requirement and Kc of Carrot

Carrot is sown at 1 December 2021 and harvested at 20 February 2022. The water required by Carrot crop during this season is 94.41 mm and the Kc value is between 0.79 to 1.16.

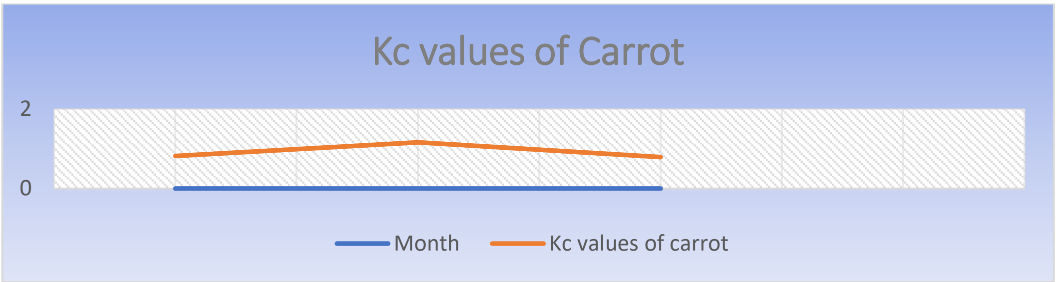

Figure 5. Crop Coefficients of Carrot.

3.9. Water Requirement and Kc of Maize

Maize crop sown at 1 march 2022 and will be harvesting at 15 July 2022. The water required by maize crop during this season is 403.07 mm and the Kc value is between 0.62 to 1.09.

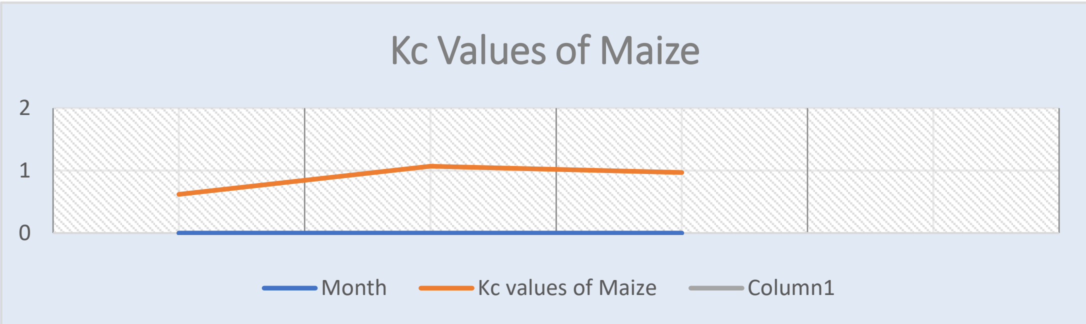

Figure 6. Crop Coefficients of Maize.

3.10. Water Requirement and Kc of Oat

Oat is sown at 1 December 2021 and harvested three times each times as it can germinate again. Las harvesting is done at 28 April 2022. The water required by Oat crop during this season is 331.89 mm and the value of Kc is between 0.66 to 1.13.

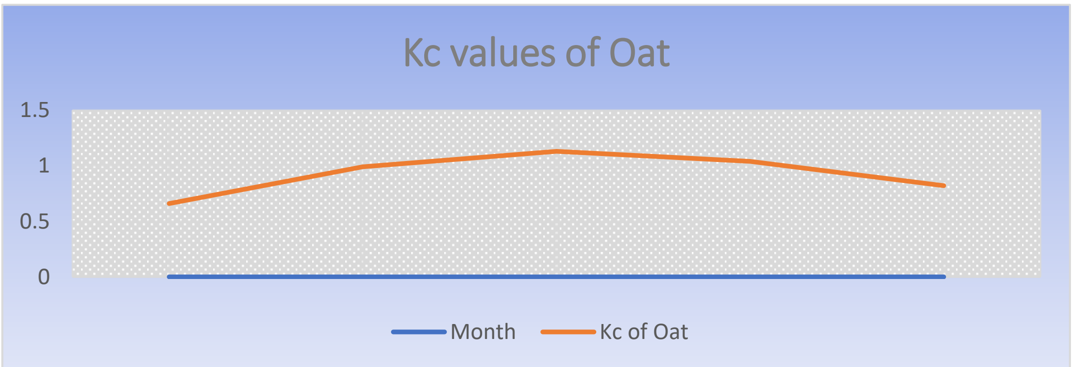

Figure 7. Crop Coefficients of Oat.

4. Conclusions

From the study it has been determined that water needs of wheat crop of variety Fakhre Bhakhar and Anaj-17 are 361.81 mm and 379.5 mm respectively. Crop coefficients or kc values of Fakhre Bhakhar variety in between 0.79 and 1.19. Crop coefficients or kc values of Anaj-17 variety in between 0.87 to 1.27 which are close enough to range of Kc values (0.2–1.5) which is suggested by FAO. The yield taken out from these two experiments is different, nevertheless. Anaj-17 output is larger than Fakhre Bhakhar in similar region farming technique. Anaj-17 yield is 491(gram per m^2) which is greater than the

Fakhre Bhakhar yield 491 (gram per m²) (gram per m²). Water required by carrot crop 94.41 mm mm and its crop coefficient taken out from the study is in between 0.79 to 1.16. Crop water demand of maize crop for hybrid variety is found to be 403.07 mm and its crop coefficient is in between 0.62 to 1.07. Water required by oat crop throughout its season is 331.89 mm and its crop coefficients is 0.66 to 1.13 which are close enough in range between the Kc values (0.9–0.85) recommended by FAO.

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